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GEO Satellites as Space Weather Sensors

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Air Force Research Laboratory
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1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
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GEO SATELLITES AS SPACE WEATHER SENSORS

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5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Cahoy, Kerri
Carlton, Ashley

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

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77 Massachusetts Avenue
Cambridge, MA 02139

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Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

We have acquired and analyzed >1 million hours of geostationary communications satellite housekeeping telemetry from commercial operators and have correlated the data with space weather observations and models. We analyzed two component types: solar cells and high power amplifiers. For amplifiers, we identified the occurrence of anomalies is not random with respect to the space weather environment. There appears is relationship to high-energy electron fluence between 10 - 21 days before the anomalies. From simulation and electron beam lab tests, we demonstrated that a potential cause may be internal charging which occurs in the amplifier chain. We also calculated on-orbit degradation of both Si and GaAs solar cells and quantified the degradation of the cells during severe solar proton events of 10 MeV protons. We compared the data with several combinations of space weather environment solar cell degradation models; predicted performance is within 1% of the observed degradation. We developed algorithms that find any unusual behavior in satellite health telemetry without requiring training data. Once identified, we collect and analyze them, along with assessing space weather observations and operational environment factors, and rank them by their their importance.

15. SUBJECT TERMS
geostationary, satellite, communications, power amplifiers, space weather, anomalies, fault detection, solar cells, telemetry

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Kerri Cahoy
					19b. TELEPHONE NUMBER *(Include area code)* 617-324-6005

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1. REPORT DATE. Full publication date, including day, month, if available. Must cite at least the year and be Year 2000 compliant, e.g. 30-06-1998; xx-06-1998; xx-xx-1998.

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GEO Satellites as Space Weather Sensors
AFOSR Grant FA9550-13-1-0099
PI: Dr. Kerri Cahoy

We have acquired and analyzed >1 million hours of geostationary communications satellite housekeeping telemetry from commercial operators and have correlated the data with space weather observations and models. Our analysis focused on two component types: solar cells and high power amplifiers. We have calculated on-orbit degradation of both Si and GaAs solar cells and quantified the degradation of the cells during severe solar proton events of 10 MeV protons [Lohmeyer, et al, 2016]. We used the calculated degradation to evaluate several combinations of space weather environment models with solar cell degradation models and found that predicted performance is within 1% of the observed degradation. These models had not previously been validated using multiple on-orbit GEO datasets.

For high power amplifiers, we conducted a root-cause analysis of solid state power amplifier (SSPA) anomalies on-board eight GEO satellites [Lohmeyer and Cahoy, 2013; Lohmeyer, et al., 2015]. From the statistical analysis, we identified that the occurrence of anomalies was not random with respect to the space weather environment, but that there appeared to be a relationship to high-energy electron fluence for periods of time between 10 - 21 days before the anomalies. From the simulations and electron beam lab tests, we demonstrated that internal charging occurs in the amplifier chain, potentially identifying a cause for the observed anomalies.

In addition to analyzing specific component telemetry, we have developed algorithms that find any unusual behavior in satellite health telemetry [Carlton, et al., 2015; Carlton and Cahoy, 2015]. Once these events have been identified, we collect and analyze them, along with assessing space weather observations and operational environment factors. Our approach statistically evaluates the telemetry stream compared to a local norm. This approach allows us to apply our algorithms to any spacecraft platform, since there is no reliance on satellite- or component-specific parameters, and it does not require *a priori* knowledge about the data distribution. We apply these techniques to individual telemetry data streams on a GEO ComSat and compile a list of unusual events for each satellite. Preliminary results include being able to identify events that affect many telemetry streams at once, indicative of a system-level event. With data from multiple satellites, we use these methods to better identify external factors. We compare event dates to known operational activities and to known space weather events. Future work includes identification of probabilistic relationships between event dates and known operational and space weather events and a component sensitivity analysis to events in an effort to validate the use of event detection algorithms for spacecraft monitoring and for environmental sensing.

We will expand upon current event detection algorithms in the areas of moving the algorithm online and incorporating learning from previous mission data. We intend to submit a white paper to AFRL on the algorithms for GEO ComSats in the interest of continued collaboration with AFRL. This effort will be augmented by support from the NASA Space Technology Research Fellowship awarded to A. Carlton (beginning in the fall of 2016).

Lohmeyer, W., R. Aniceto, A. Carlton, and K. Cahoy, “Solar Array Degradation on Geostationary Communications Satellites: The Quantification of Annual Degradation and Degradation over Solar Proton Events,” submitted for publication in the Journal of Solar Energy, Jan. 2016.

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Auxiliary information and response to our inquiry on format of report.

Dear Kerri Cahoy,

Our records at AFOSR indicate that your Grant FA9550-13-1-0099, "GEO Satellites as Space Weather Sensors," is nearing its end and will be closing on14 FEBRUARY 2016.

As of 15 January 2016, AFOSR will no longer accept any modification requests and will begin the Grant close-out process.

We encourage you to begin preparing your Final Performance Report and SF 298 form, which are due within 90 days of the end of your Grant.

Details about submitting your Final Performance Report can be found on theAFOSR website: http://www.wpafb.af.mil/library/factsheets/factsheet.asp?id=9389

Be sure to coordinate with your Program Officer regarding their expectations of your Final Performance Report content.

Regards,

The AFOSR Business Team

Email from Julie Moses:

All we need for the closeout/final report is an abstract-length (250 words) summary of the accomplishments of the research.

1.

1. Report Type

Final Report

Primary Contact E-mail
Contact email if there is a problem with the report.

kcahoy@mit.edu

Primary Contact Phone Number
Contact phone number if there is a problem with the report

650-814-8148

Organization / Institution name

MIT

Grant/Contract Title
The full title of the funded effort.

GEO SATELLITES AS SPACE WEATHER SENSORS

Grant/Contract Number
AFOSR assigned control number. It must begin with "FA9550" or "F49620" or "FA2386".

FA9550-13-1-0099

Principal Investigator Name
The full name of the principal investigator on the grant or contract.

Kerri Cahoy

Program Manager
The AFOSR Program Manager currently assigned to the award

Julie Moses, Kent Miller

Reporting Period Start Date

02/15/2013

Reporting Period End Date

02/14/2016

Abstract

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Archival Publications (published) during reporting period:

Lohmeyer, W., R. Aniceto, A. Carlton, and K. Cahoy, "Solar Array Degradation on Geostationary Communications Satellites: The Quantification of Annual Degradation and Degradation over Solar Proton Events," submitted for publication in the Journal of Solar Energy, Jan. 2016.

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Changes in research objectives (if any):

None

Change in AFOSR Program Manager, if any:

Extensions granted or milestones slipped, if any:

None

AFOSR LRIR Number

LRIR Title

Reporting Period

Laboratory Task Manager

Program Officer

Research Objectives

Technical Summary

Funding Summary by Cost Category (by FY, $K)

	Starting FY	FY+1	FY+2
Salary			
Equipment/Facilities			
Supplies			
Total			

Report Document

Report Document - Text Analysis

Report Document - Text Analysis

Appendix Documents

2. Thank You

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